In-house Engineering for Resolution of Chronic 4th Stage High Discharge Pressure Limitation on Carbon-dioxide Reciprocating Compressor

Author: Mr. Ali Shallwani
Designation: Machinery Engineer
Organization: Engro Fertilizers Limited
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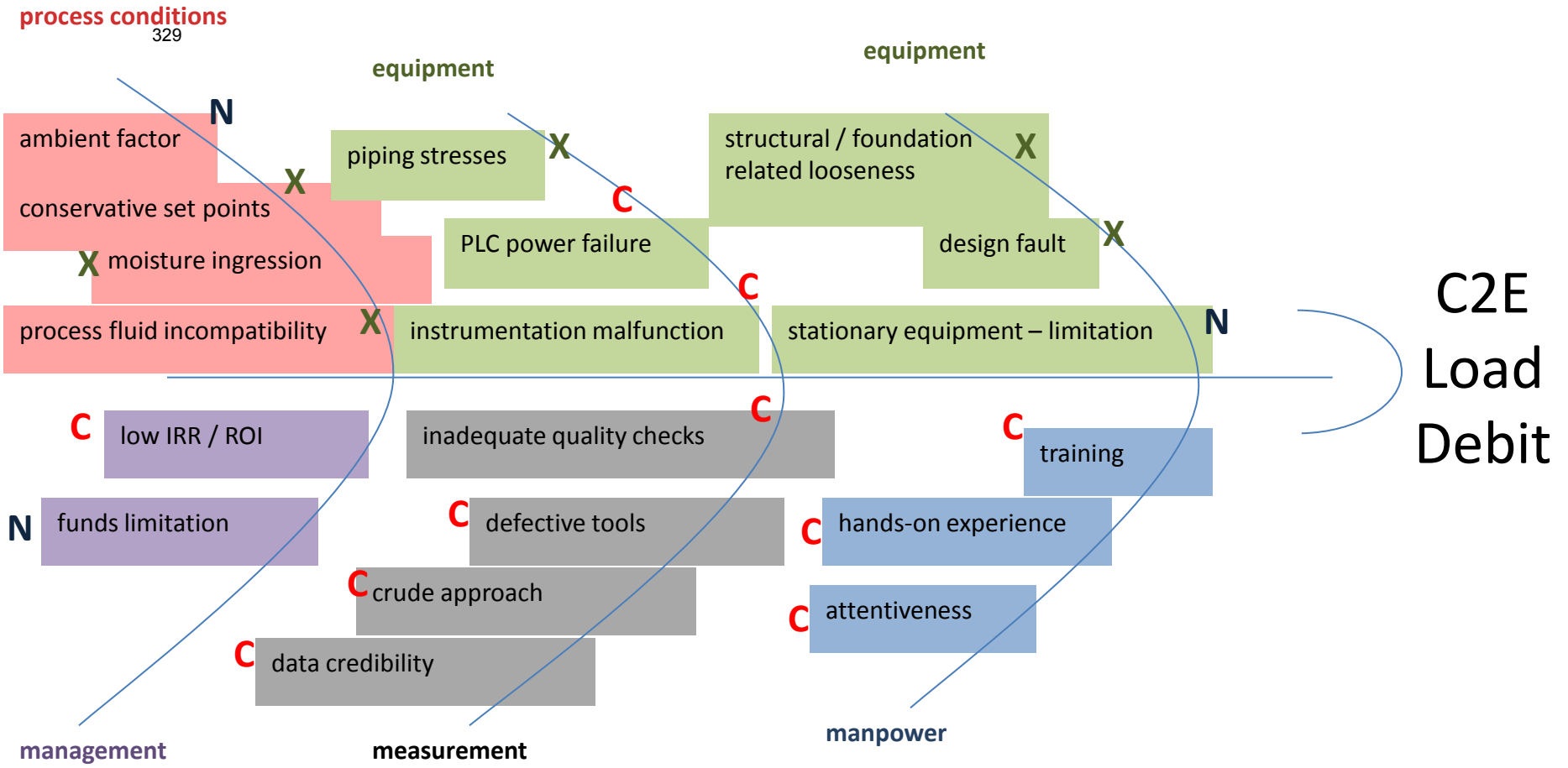
Problem Statement

- Carbon-dioxide reciprocating compressor tagged C-2E had chronic issue of high 4th stage discharge pressure. The machine has no stand-by.
- Only 5th stage piston rings were affected because of the two reasons i.e. this is high pressure stage, and it is suspected that the performance of separators have degraded.
- The normal operating discharge pressure is 940psig which increased to 990psig.
- The increase in discharge pressure to the limit near pressure safety valve set-point (1010psig) forced the low-load operation of the compressor.
- Average CO_2 flow rate through compressor is 1250kscfh, which was reduced to 1100kscfh. This debit is equivalent to an opportunity lost cost of USD 37,000 on daily basis.

Analysis

- Through Cause and Effect diagram – we inferred that most probable cause behind high 4^{th} stage discharge pressure can be the failure 5^{th} stage piston rings. Other probable reason included discharge valve failure, high 4^{th} stage suction pressure, tight bump clearances etc.
- Seeking an opportunity, the machine was S/D and 5^{th} stage piston assembly was inspected, and 4^{th} stage discharge valves were leak-tested.
- During inspection, all the piston rings were found missing, and the rider rings were found damaged on the 5^{th} stage piston.



Process Fuild Incompatibility / Design Fault – 2nd Stage Piston Metallurgy, 5th Stage Piston Rings Failure

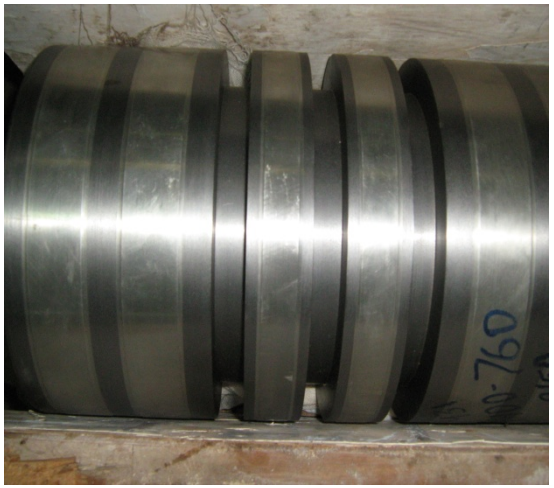
Conservative Set Points – 2nd Stage Discharge Temperature Limitation, 4th Discharge Pressure Limitation

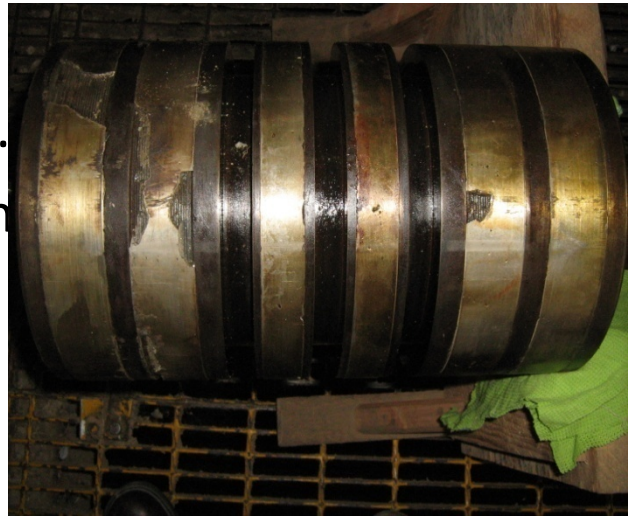
Structural / Foundation Related Looseness + Piping Stresses – Structural and Piping Survey

Moisture Ingression – Running Fluid Analysis 24/7, Process Parameters Evaluation by Consultants

Analysis

- Piston rings act as seal between the two compression compartments on the cylinder.
- Upon the failure of these rings, the gas from discharge stroke compartment will leak into suction stroke compartment.
- The ingression of high pressure gas will restrict the inlet stream of gas, and this resistance will cause an increase in the discharge pressure of the previous 4th stage.
- The failure of piston rings corresponds to th drop in the overall efficiency of the reciprocating compressor.

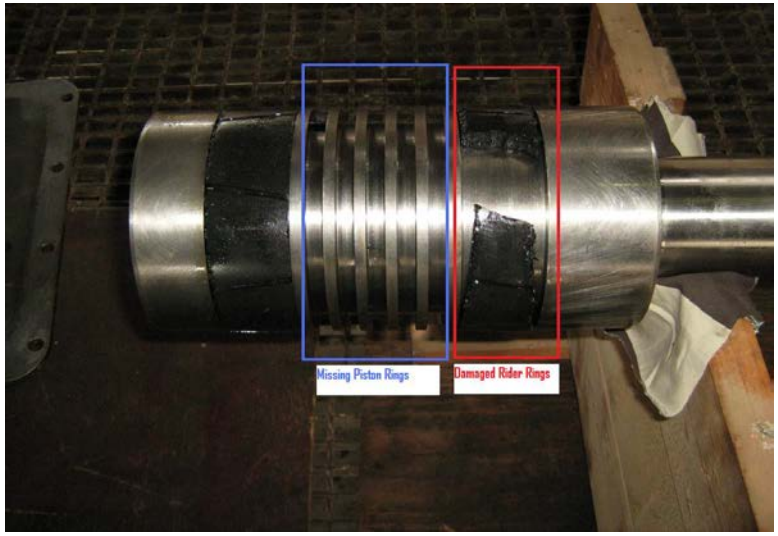


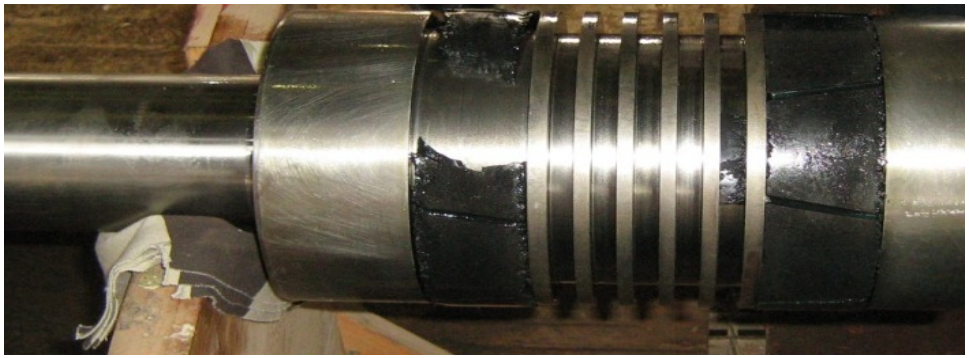


Analysis

- Upon, disassembly of 5th stage – surprisingly all the 05 piston rings were found missing.
- No traces of piston rings were neither found inside the cylinder nor on the suction/discharge valves.
- Rider Rings were found in damaged condition – as if eroded.

Operating Conditions:
suction pressure - 960psi
discharge pressure - 2400psi
suction temp - 116F
discharge temp - 260F
Service:
Carbon dioxide
Material:
Piston Rings / Rider Rings:
carbon filled teflon elastomer





Analysis

- Occurrence:
  - once every 2years (since 2002 – this refurbished machine was commissioned in 1998)
- Probable Reason:
  - moisture mixing with CO2 form carbonic acid – CFTE – Carbon filled Teflon Elastomer is susceptible to such service with time
  - Carbamate (intermediate product of Urea reaction) carryover – highly corrosive – this solid material can damage non-metallic piston rings
- Trouble-shooting:
  - address moisture and Carbamate carryover issues – this required inspection of knock-out drums
  - for production facility optimization – to operate the compressor at normal load – and to prevent unloading of machine due to high pressure limitation
  - For this purpose it was concluded that the non-metallic piston rings shall be replaced with metallic-piston rings – wear rings / rider rings are not as critical as piston rings during machine run, and does not limit operation / performance of the machine. The purpose of rider rings is to avoid contact between piston and liner during stand-still condition.

Analysis

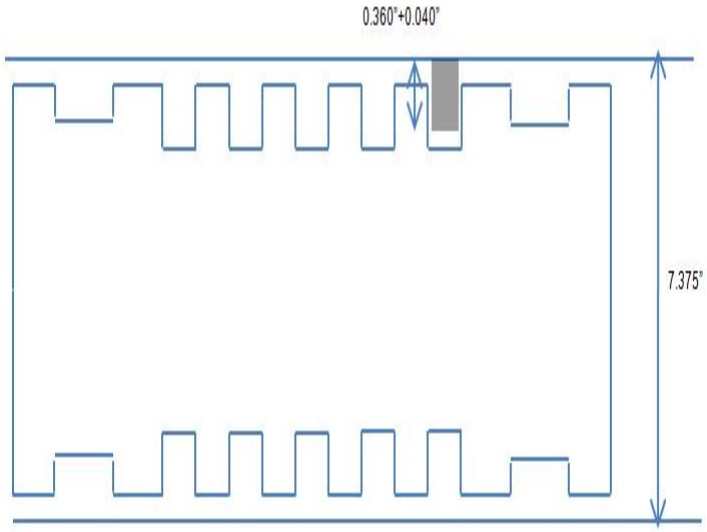
- Material selection, and the sizing of the rings were the next challenge for the team
- Follow practices were employed based upon best-practices of our site, and engineering references
- OEM agreed upon our recommendation – and provided us with necessary information about the cut geometry
- Bronze was selected as material for piston rings – for following reasons,
  - ease of machining – no special heat requirement
  - commonly used in other machines at Engro for the same purpose
  - material availability in our Warehouse
- Material Specifications
  - Aluminium Bronze, UNS C95200
  - ASTM B148-9A/ SB-62

Analysis

- Dimensional Details
  - OD of the Bronze ring shall be equal to Cylinder ID –this was inferred based upon logical approach to seal the gas through the cylinder such that no gap between the piston rings and cylinder exists
  - Cylinder liner metallurgy is Cast Iron – and Bronze being relatively softer material will act as sacrificial one without any physical damage to liner and piston assembly.
  - The gap between metallic piston rings pieces was kept at 2-3times the gap between non-metallic rings. The gap for metallic ring was kept at an average of 0.025”.
  - The thickness for the metallic rings were kept at 0.7times the thickness of non-metallic rings – this dimension was crucial to protect piston ring grooves

Analysis

- Dimensional Details
  - Overlapping between the piston ring and piston ring groove is important –to restrict the free movement of the former. This was maintained between 0.350” and 0.400” based upon best practices. The net radial thickness of the piston ring was therefore 0.350” (overlapped length)+0.030”(difference in Cylinder ID and Piston OD).
- Piston Ring Design
  - 03piece with 45degree cut
- Forced Feed Lubrication
  - Forced feed lubrication was increase from 8dpm to 16dpm – based upon our experience with the other reciprocating compressors running with metallic piston rings and rider rings



Constants:

Piston Ring Groove:	Piston Rod Sizes:	Cylinder Bore:	Piston Size
Width: 0.500”	ø : 4.000”	ø: 7.380”	ø: 7.247”
Depth: 0.532”			

Before

Piston Rings

Material:	CFTE
Unit:	01 piece

Sizes -

Radial Thickness:	0.490”
Axial Width:	0.500”
End Gap:	0.025”

Now

Piston Rings

Material:	Bronze
Unit:	03 piece **(45 degree cut)**

Sizes -

Radial Thickness:	0.400”
Axial Width:	0.500”
End Gap:	0.020” – 0.030”

Conclusion

- The outcome of the in-house engineering was a source of contentment and satisfaction for our team and the company.
- Since Sept, 2009 to-date the stage has never been attended, 4th discharge pressure remain stable.
- We plan to inspect the stage in our upcoming Turnaround-2012. The vibration at cylinder head is running at 0.4ips – as per previous history this is in the lowest range ever. This low vibration confirms remote possibility / occurrence of metallic contact / rubbing between the rotating and stationary parts.
- Beside, equipment reliability and sustained operation – this exercise offered convenient and cost-effective approach for piston ring
- The entire cost of manufacturing for the 1set (05rings) of metallic piston rings is 10% of the total price of the OEM manf. non-metallic piston rings.
- This exercise prevented occurrence of low-load operation on this compressor (for this specific reason) from Sept, 2009 to-date.
- Through this in-house modification – Savings worth USD 150k has been realised – the critical of continuous production has gone extreme in the view of high Urea production demand in Pakistan.